M4.02.00 Cement Concrete.

Cement concrete shall be composed of specified proportions by the mass of cement, aggregates, water and approved additives to form a homogeneous composition.

Cement concrete shall be designated by class according to strength, cement factor, coarse aggregate size, entrained air content, slump, and by the mass for light-weight concrete. The classes of concrete to be used shall be designated on the plans or in the specifications for the particular work. The Contractor will furnish to the Engineer, for approval, a specific job mix formula for the particular uniform combination of materials and sources of supply to be used on each project complete with test results from trial batches. A new job mix formula shall be supplied any time any source of material has been changed.

Classifications of Concrete Mixes

28-Day Compressive Strength (MPa)	Minimum Cement Content (Kilograms per Cubic Meter for Coarse Aggregate)		
	10 mm	20 mm	40 mm
20	335300		280
25	365335		310
30	425390		335
35	450420		400
40	510475		450
45	535 500		480
50	565530		500
55	620585		560
% Entrained Air (±1.0%)	7.06.0		5.0

All concrete shall contain a water reducing admixture.

Concrete which will be subjected to conditions of severe exposure will be minimum 30 MPa with air-entrained content of 7.0 ± 1.0% when so specified.

The use of an approved additive other than air entraining (AASHTO M 154) or water reducer (AASHTO M 194, Type A) shall require written approval of the Engineer and additives shall not affect a change in the minimum cement content. The minimum cement content can be changed only with the prior written approval of the Engineer.

Alkali Silica Reactivity - Resistant Portland Cement Concrete

All cement concrete masonry and precast/prestressed concrete products shall be alkali silica reactivity-resistant. Proportion Portland Cement Concrete mixes to include materials that meet either the aggregate requirement or Alkali-Silica Reactivity (ASR) mitigation criteria listed below. Cement mill test reports from certified laboratories shall be provided that show the materials' source, composition and the cement alkali content expressed as sodium oxide equivalent[(a)] not to exceed 1.4%. Certified test reports according to test procedures as specified in Table A will be required to be submitted with the trial batch submission to the Research and Materials Division for approval every year or whenever the source of material is changed.

Select nonreactive aggregates that meet all the criteria of Table A. Mitigate the mix as described below when non-reactive aggregates are unavailable. If nonreactive aggregates are used for portland cement concrete mix, 15% by mass of the cementitious content shall be fly ash meeting AASHTO M295, Type F.

Select a material or a combination of materials that meet the criteria shown in Table B to mitigate ASR when concrete mixes must be proportioned with reactive aggregates. Perform verification testing according to AASHTO T303 - Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction and ASTM C295 - Petrographic Examination of Aggregates for Concrete to determine the effectiveness of the resulting mix design against ASR. Use the same proportion of cement and

pozzolan for each test mixture as that proposed for the actual mix design. Provide the Research and Materials Division with certified documentation of the mixtures' effectiveness to control ASR.

Table A
Tests and Criteria for Proposed Aggregates

Procedure	Description	Limits
AASHTO T 303 Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction	Mean mortar bar expansion at 14 days	0.08% maximum metamorphic aggregate 0.10% maximum all other aggregates
	Perform a polynomial fit[(b)] of 4, 7, 11, and 14 days to determine reliability of results	Repeat the AASHTO T303 if r^2 is less than 0.95
ASTM C 295 Petrographic Examination of Aggregates for Concrete	Optically strained, microfractured, or microcrystalline quartz	5.0% maximum[(c)]
	Chert or chalcedony	3.0% maximum[(c)]
	Tridymite or cristobolite	1.0% maximum[(c)]
	Opal	0.5% maximum[(c)]
	Natural volcanic glass	3.0% maximum[(c)]

Table B
Mitigation Methods for ASR in Portland Cement Concrete

Material	Specification	Cementitious Material Percentage[(d)]
Low alkali cement[(e)]	AASHTO M 85	100%
Fly ash - Class F	AASHTO M 295	15% minimum to 30%[(f)] maximum
Silica Fume[(g)]	AASHTO M 307	6% ± 1%[(h)]
Slag Grade 100 and 120	AASHTO M 302	25% minimum to 50% maximum

Notes:
(a) Na_2O equivalent = $\%Na_2O + 0.658\ (\%K_2O)$
(b) Use a second order polynomial of $\%Exp = A^o + A^1SQRT(t) + A^2t$. See publication SD92-04-F.
(c) Based on the total aggregate sample.
(d) Measure this minimum content of cementitious material as percent by weight of cement plus pozzolan.
(e) This single criterion is not effective in all cases in remediating ASR. Low alkali cement (0.60% maximum[(a)]) must be used in combination with other pozzolanic materials in Table B.
(f) Fly ash, Type F, shall replace 15% by weight of the design cement content, and any additional fly ash will be considered as fine aggregate.
(g) Silica fume shall only be used in silica fume cement concrete masonry.
(h) The total amount of Type F fly ash and silica fume shall constitute 20% by weight of the design cement content, and any additional fly ash will be considered as fine aggregate.

M4.02.01 Cement.

Cement for concrete shall be the kind and type designated on the plans or in the specifications for the particular work. If no type is specified either Type I, IA, IP, IP-A or Type II, IIA shall be furnished except that cement for exposed bridge deck concrete or concrete exposed to sea water shall be Type II or IIA.

When high early strength concrete is required it shall be obtained by using Type III or by adding an accelerator meeting AASHTO M 194.

Cement shall not exhibit a flash set or cause an abnormal initial rise of temperature when mixed with water. It shall maintain its full plasticity and fluidity during the period required for placing the concrete.

The temperature of the cement at the time of mixing shall not exceed 65 °C.

When tested at the mill, no cement shall be shipped to the work until it has passed the 7 day test, unless otherwise directed. At least 12 days from the time of sampling shall be allowed to the completion of the required 7 day test.

Each shipment, regardless of quantity, shall be accompanied by a certified Mill Test Report, three copies of which shall be furnished to the Engineer before the cement may be incorporated in the work. Cement furnished without a current Mill Analysis Report shall not be used in the work until the Engineer has had sufficient time to make appropriate tests and has approved the cement for use. A current Certificate of Compliance for concrete admixtures, fly ash, silica fume, and slag based on test results shall be available for the inspector prior to production.

Cement of a uniform color shall be used in all exposed concrete of any structure.

M4.02.02 Aggregates.

A. Fine Aggregates.

Sand shall be composed essentially of clean, hard, strong, durable and impermeable particles, resistant to wear and frost, inert to cement and water, reasonably free from structurally weak grains, organic matter, loam, clay, silt, salts, mica or other fine materials that may affect bonding of the cement paste. Sand shall be taken from a natural deposit. The sand particles shall be relatively spherical in shape, and shall have gritty surfaces.

Sand for cement concrete shall be properly washed to satisfactorily remove deleterious materials and surface coatings, and shall be stockpiled after washing for a period as long as necessary to drain off all excess water.

The sand shall conform to the following requirements:

	AASHTO Test Method	Maximum Percent by Mass
Clay Lumps and Friable Particles	T 112	3.0
Coal and Lignite	T 113	0.5
Materials Passing 75 µm Sieve	T 11	3.0
Organic Impurities	T 21	*Pass
Soundness (Na_2SO_4) - 5 Cycles	T 104	10

*Sand when tested for mortar making properties as specified above shall produce a compressive strength, at any period of time, equal to or greater than that developed by mortar of the same proportions and consistency made of the same cement and sand after the sand has been treated in a 3% solution of sodium hydroxide in accordance with AASHTO T 71.

Sand not conforming to requirement specified above for organic impurities shall be rejected unless the 28 day strength tests show the color is due to impurities not detrimental to the strength of the concrete.

The sieve analysis of the sand shall show it to be well graded and conforming to the following:

Sieve Designation	Fine Aggregate Minimum	Fine Aggregate Maximum
9.5 mm	100	–
4.75 mm	95	100
1.18 mm	45	80
300 µm	10	30
150 µm	2	10

75 µm	0	3

The fineness modulus of fine aggregate shall be not less than 2.5 and not greater than 3.0. For the purpose of determining the degree of uniformity, a fineness modulus determination will be made upon representative samples from any one source. Fine aggregate from any one source having a variation in fineness modulus greater than 0.20 either way from the representative sample will be rejected.

Samples for tests of fine aggregate will be taken under the direction of the Engineer from approved storage piles at the site of the batch plant or from approved storage piles at the producing pit.

The fineness modulus of fine aggregate shall be determined by adding the cumulative percentages, by weight, of materials retained on U.S. Standard Sieves 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm and dividing by 100.

Fine aggregate failing to pass the minimum requirements for material passing the 300 µm and/or 150 µm sieves may be used, provided an approved inorganic fine material is added to correct the deficiency in grading.

Sand for cement mortar shall conform to the requirements specified above except that the compressive strength shall not be less than 85% of that developed by mortar of the same proportions and consistency made of the same cement and sand after the sand has been treated in a 3% solution of sodium hydroxide in accordance with AASHTO T 71. The sieve analysis shall conform to the following requirements:

Sieve Designation	Minimum	Maximum
2.36 mm	100	–
300 µm	15	40
150 µm	2	10
75 µm		3

B. Coarse Aggregates.

Coarse aggregate for cement concrete shall consist of crushed rock or screened gravel, and shall be composed essentially of clean, hard, strong, and impermeable particles, resistant to wear and frost, and free from deleterious amounts of organic matter, loam, clay, salts, mica, and soft, thin, elongated, laminated or disintegrated stone, and it shall be inert to water and cement. Where finishing of the concrete is to be done by hammering or any other method that breaks the surface of the concrete, only crushed rock shall be used for coarse aggregate.

The aggregates shall conform to the requirements shown below.

Gravel stone shall be thoroughly washed to remove impurities if surfaces are coated with dust.

A deleterious amount of thin and elongated stones will be considered any amount in excess of 15% of the total mass. Thin stones shall be considered to be such stone whose average width exceeds four (4) times their average thickness. Elongated stones shall be considered to be such stone whose average length exceeds four (4) times their average width.

	AASHTO Test Method	Maximum Percent by Mass
Clay Lumps and Friable Particles	T 112	2.0
Chert (Less than 2.40 Sp. Gr. SSD)*		3.0
Sum of Clay Lumps, Friable Particles and Chert (Less than 2.40 Sp. Gr. SSD)*		3.0
Material Finer than 75 µm Sieve	T 11	1.0
Coal and Lignite	T 113	0.5
Percent of Wear (Los Angeles Abrasion Test)	T 96	45 except 30 for all concrete 35 MPa and a
Sodium Sulphate Solution Soundness (5 Cycles)	T 104	10

*These limitations apply only to aggregates in which chert appears as an impurity.

C. Sieve Analysis.

When tested by U.S. Standard laboratory sieves, coarse aggregate for cement concrete shall be blended from stone sizes to meet the graduation requirements for each designation listed below. The limits shown in the table define master ranges of variation for general application and are minimum and maximum in each case. To insure uniformity of material used on any one job or project, the range of variations may be reduced to 1/2 of the range upon determination of the character and source of the materials that the Contractor proposes to furnish.

Percent by Mass Passing (AASHTO T 27)

Designation and	40 mm		20 mm		10 mm	
Nominal Sieve Size	Min	Max	Min	Max	Min	Max
37.5 mm	90	100				
19.0 mm	35	60	90	100		
12.5 mm					100	
9.5 mm	10	25	20	50	85	100
4.75 mm	0	5	0	10	10	30
2.36 mm			0	5	0	10
1.18 mm					0	5

Stone retained on the largest sieve shall be within an oversize tolerance of 6.30 millimeters.

40 millimeter aggregate shall be proportioned in two or more sizes, separately weighed in the mix. The combined grading as proportioned in the mix shall meet the grading requirements for 40 millimeter coarse aggregate, as determined by actual test.

20 millimeter aggregate may be proportioned in two sizes or processed to the specified gradation.

For use in mass concrete the Engineer may allow the use in 40 millimeter aggregate of not more than 30% of coarse aggregate passing 56.5 millimeter and retained on a 37.5 millimeter sieve, provided such aggregate is separately proportioned as an additional size.

M4.02.03 Lightweight Aggregates.

Lightweight aggregates for Structural Concrete shall meet AASHTO M 195.

M4.02.04 Water.

Water for use in cement concrete shall be clean, clear and free from deleterious amount of oil, acid, alkali, salts and organic matter.

The water shall exhibit no deleterious effect upon the strength, setting, or soundness of the cement. It shall conform to the following requirements:

1. pH 3.0-11.7
2. Total Solids:
   a) Organics 0.01% maximum
   b) Inorganics 0.10% maximum
   c) Sulphate 0.05% maximum

Testing of the water shall be in accordance with AASHTO T 26.

M4.02.05 Cement Concrete Additives

Air-entraining admixtures, water-reducers, retarders, etc., shall conform to the following specifications:

A. Air-entraining admixtures, AASHTO M 154
B. Retarders, AASHTO M 194
C. Water reducers, AASHTO M 194

M4.02.06 Proportioning.

Concrete shall be proportioned with the specified minimum cement content for each class and shall be mixed to the required consistency as determined by standard slump test AASHTO T 119.

A. Proportioning by Mass.

Cement and aggregates shall be proportioned by mass in an approved manner. Scales shall be calibrated and sealed by the proper authority within the preceding year, or following any reassembly, or as the Engineer may direct.

B. Scope of Control for Proportioning.

The responsibility of the Department is confined to the inspection of the following four factors controlling the mix:

1. Minimum Cement Content and Minimum Strength.

The cement proportion is subject to adjustment and approval by the Engineer in order to insure compliance with minimum strength requirements. Standard field test specimens (AASHTO T 23) shall be taken on the job and the Contractor shall be required to add additional cement as directed by the Engineer if test specimens, strength fails to meet the requirements of ASTM C 94, Section 17.

No claims shall be allowed for extra cement or extra concrete due to variations in materials, proportioning, dimensions, shrinkage, waste and similar causes. The Contractor is advised to anticipate a normal loss in yield of 1% or 2% due to the foregoing causes.

The volume of plastic concrete in a given batch shall be determined from the total mass of the batch divided by the actual mass per cubic meter of the concrete. The total mass of the batch shall be calculated as the sum of the masses of all materials including water. The mass per cubic meter shall be determined in accordance with the Method of Test for Weight per Cubic Meter Yield and Air Content (Gravimetric) of Concrete (AASHTO T 121).

2. Consistency.

The Contractor shall uniformly regulate the consistency of the mix to the slump directed by the Engineer. The Engineer may reject all batches not conforming to this requirement and the Contractor shall receive no additional compensation.

The general requirements in regard to consistency are as follows:

Mass Concrete	50 ± 13 mm slump
Exposed Bridge Deck Concrete	63 ± 13 mm slump
Reinforced Concrete	75 ± 25 mm slump
Very Constricted Placement Conditions	100 ± 25 mm slump
Pump Concrete	100 ± 25 mm slump
Tremie Concrete	150 ± 25 mm slump

When the specified slump is less than 75 millimeters the tolerance shall be plus or minus 13 millimeters. When the specified slump is 75 millimeters or greater the tolerance shall be plus or minus 25 millimeters. The Engineer will specify the lowest slump with which it is practical to properly place and consolidate the mix within the forms.

3. Workability.

The Engineer may vary the proportion of fine aggregate in order to regulate the workability or density of the mix, making an equivalent change in the course aggregate to keep the yield constant.

4. Air Content.

The air content of the concrete by volume shall be as shown in the table above when tested in accordance with AASHTO T 152. A tolerance of plus or minus 1% in the above percentages will be allowed.

C. Automatic Proportioning Plants.

All plants shall be equipped with an approved automatic weighing, cycling and monitoring system installed as part of the batching equipment. Each plant shall include equipment for accurate proportioning

batches containing the various components by mass or by volume for admixtures and water in the proper sequence and for controlling the sequence and timing of mixing operation. The automatic proportioning system shall be capable of consistently delivering each constituent within the tolerances indicated in M4.02.07. Interlocks shall be provided which will hold or delay the automatic batch cycling whenever the batched quantity of any component is not within the specific weight tolerance, when any aggregate bin becomes empty or when there is a malfunction in any portion of the control system. The mass setting and time controls shall be so equipped that they may be locked when directed by the Engineer.

The weighing equipment shall be so arranged that the batch plant operator can conveniently observe all scales from his/her operation station.

The controls shall be set so that:

1. The batcher inlet gates cannot be opened while the discharge gates are open.
2. The batcher discharge gates cannot be opened:
    a) Until the full batch masses are registered on the scales;
    b) While the hopper is being filled;
    c) If batch masses are over or under the delivery tolerances specified on M4.02.07.
3. A new batch cannot be weighed until the hopper is entirely empty of the previous batch and all scales have returned to zero.

Discharge chutes shall be so arranged that they are not suspended from any part of the weighing system and so that no materials will lodge therein or be lost on discharge.

Each weighing unit shall include a springless dial which shall indicate the scale load at all stages of the weighing operation from zero to full capacity.

If at any time the automatic proportioning system becomes inoperative, the plant will be allowed to batch materials manually for a period not in excess of 2 working days. Manual batching for longer periods will require written permission of the Engineer. All plant scales shall be tested at the expense of the producer by a competent scale technician as follows:

1. Annually prior to use in Department work.
2. At any time ordered by the Engineer.

D. Admixture Dispensing Systems.

Plants shall be equipped with a separate dispensing system necessary to incorporate each of the required admixtures into the concrete. At least two admixture dispensing systems shall be required for plants supplying structural concrete.

E. Recording the Batching.

All concrete batching plans equipped with automatic proportion systems shall have digital recording instruments approved by the Engineer which shall be so located as to be readily accessible and readable to the operator from his/her normal work station. The recording instruments shall be designed to record the quantities of each aggregate component, cement, fly ash (when used), water and the presence of admixture for each batch of concrete produced. All records of batches shall show the batch number, the day, the month, the year, and time of day to the nearest minute for each batch and they shall be imprinted on the record so that each batch may be permanently identified. The Department shall be provided with a clear and legible copy of all batch records.

Cement, fly ash, and aggregate component weight quantities shall be recorded separately. Water may be removed by mass or volume.

Masses and/or volumes shall be recorded as indicated on the batching scale or meter within an accuracy of ± 1 scale or meter gradation. The minimum recorder resolution shall be equivalent to or less than minimum gradation on the scale or meter, unless otherwise approved by the Engineer. When the automation system is capable of producing other than standard size batches (full, half, or quarter cubic meter increments), the recoordination requirements shall be in accordance with written directives from the Engineer.

Each plant site shall be equipped with an approved instrument capable of automatically applying a time-date stamp to each delivery ticket as the delivery vehicle departs from the plant site.

M4.02.07 Measuring Materials.

A. Cement shall be measured by mass or in bags of 42 kilograms each. When fly ash or slag is specified in the mix design, it may be weighed cumulatively with cement. Cement should be weighed before fly ash or slag. When cement is measured by mass, it shall be weighed on a scale separate from those used for other materials, and in a hopper entirely free and independent of the hoppers used for weighing the aggregates.

All beam type scales for weighing cement shall be equipped with a tare beam. When cement is measured in bags, no fraction of a bag shall be used unless weighed. The cement as weighed shall be within minus 0% and plus 4% of required mass.

B. Aggregates shall be measured by mass. Batch masses shall be based on dry materials and shall be the required masses of dry materials plus the total mass of moisture (both absorbed and surface) contained in the aggregate. The individual aggregates as weighed shall be within ± 2% of required mass.

C. Mixing water shall consist of water added to batch, ice added to batch, water occurring as surface water on the aggregates, and water introduced in the form of admixtures. Water shall be measured by volume or by mass. The device for the measurement of the water shall be readily adjustable and shall be capable of being set to deliver the required amount and cut off the flow automatically when this amount has been discharged. Under all operating conditions the device shall have an accuracy within 1% of the quantity of water required for the batch. The device shall be so arranged that measurements will not be affected by variable pressures in the water supply line. Measuring tanks shall be of adequate capacity to furnish the maximum mixing water required and shall be equipped with outside taps and valves to provide for checking their calibration unless other means are provided for readily and accurately determining the amount of water in the tank. All wash water must be removed from truck mixers or agitators. All water measuring systems shall be capable of discharging total quantity of measured water into the mixer drum in a time not greater than one-third of the specified mixing time.

D. Dry admixtures shall be measured by mass, and paste or liquid admixtures by mass or volume, within a limit of accuracy of 3%. When admixtures are used in small quantities in proportion to the cement, as in the case of air-entraining admixtures, mechanical dispensing equipment shall be used.

M4.02.08 Plant and Equipment.

The plant and equipment shall be subject to approval by the Engineer to insure satisfactory prosecution of the work without delay.

A. Batching Plant.

1. Bins with adequate separate compartments for fine aggregates and for each required size of coarse aggregate shall be provided in the batching plant. Each compartment shall be designed to discharge efficiently and freely into the weighing hopper. Means of control shall be provided so that, as the quantity desired in the weighing hopper is being approached, the material may be added slowly and shut off with precision. Weighing hoppers shall be constructed so as to eliminate accumulation of tare materials and to discharge fully.

2. Fly ash shall be stored at the batch plant in a separate storage or holding bin and shall be protected from rain and moisture.

3. Scales for weighing aggregates and cement shall be of either the springless-dial type or the load cell type and shall indicate the load at all stages of the weighing operation from zero to full capacity. They shall conform to the applicable sections of the current edition of the National Bureau of Standards Handbook 44, Specification, Tolerances, and other Measuring Devices, except as may be otherwise specified. They shall be accurate within one half of 1% under operating conditions. Ten 22 kilogram masses shall be available at the plant at all times for checking accuracy. All exposed fulcrums, clevises, and similar working parts shall be kept clean. When beam-type scales are used, provisions shall be made for indicating to the operator that the required load in the weighing hopper is being approached; the device shall indicate within the last 90 kilograms of load and within 22 kilograms of overload. All weighing and indicating devices shall be in full view of the operator while charging the hopper and he/she shall have convenient access to all controls.

4. The materials, including admixtures, shall be proportioned by automatic proportioning devices, approved by the Engineer. The automatic proportioning equipment shall be installed in an area enclosed for protection against dust and inclement weather.

B. Testing Facilities.

A weatherproof building or room shall be furnished at the site of the producing plants suitable for the housing and use of equipment necessary to carry on the various tests required and for recording and processing test results. This building shall be for the exclusive use of the Engineer or his/her representative for testing and recording purposes. The building or room shall have a least dimension of 2.1 meters and a minimum of

20 square meters. Windows and doors shall be adequately screened and satisfactory lighting and heating shall be provided for a 24 hour day and be supplied with water. The room shall have adequate ventilation and be

air conditioned in the warm months to provide a minimum of 23.9 °C. A table, chairs, desk, work bench, file cabinet, electronic calculator, and a minimum of two 2.27 kilogram fire extinguishers shall be provided.

If the Engineer permits, the testing facility may be part of another building in which case it shall be entirely partitioned off from the remainder of such building.

Testing equipment conforming to current AASHTO standards and meeting the approval of the Engineer shall be furnished as follows and installed in the building for use in testing the materials (and admixtures) supplied by the Plant for the work:

1 Fine Aggregate Sieve Shaker, power driven, for 200 millimeter minimum diameter sieves.

1 Each of the following standard 200 millimeter minimum diameter square opening sieves: 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 300 µm, 150 µm, and 75 µm with pan and cover.

1 Sample Splitter with a minimum capacity of 0.03 cubic meter. It shall be of the clam shell type and the chute width shall be adjustable from a minimum of 12.5 millimeters to 50 millimeters.

1 Solution Balance, 20 kilogram capacity, weighing directly to 1 gram, with two weighing beams and a taring beam; tare capacity to be 2 kilograms; weight beams to read 1000 grams by 100 gram divisions and 100 gram by 1 gram divisions. Additional matching weights (one - 1 kg, two - 2 kg, one - 5 kg, and one - 10 kg) shall be provided to fulfill capacity of 20 kilograms. The platform to be 280 millimeters diameter. An electronic, direct reading, top loading, 20 kilogram minimum capacity, balance with a precision of 0.1 gram may be substituted for the solution balance.

1 Approved Scale with a minimum capacity of 2000 grams and with a sensitivity of 0.50 grams. An electronic, top-loading balance, with a capacity of 2000 grams minimum, and reading to 0.1 gram may be used in place of the scale.

1 Approved Dial Thermometer, range of 10 °C to 260 °C.

1 Approved Hot Plate.

Approval of a plant will be contingent upon approval of the aforementioned requirements for Plant Laboratory, including the building and appurtenances, furnishings, facilities including heat, light, power and water, the testing equipment and any other incidentals.

M4.02.09 Mixers and Agitators.

A. Mixers may be stationary mixers or truck mixers. Agitators may be truck mixers or truck agitators. Each mixer and agitator shall have attached thereto, in a prominent place by the manufacturer, a metal plate or plates on which is plainly marked the various uses for which the equipment is designed, the volume of the drum, the capacity of the drum or container in terms of the volume of mixed concrete and the speed of rotation of the mixing drum or blades. Stationary mixers shall be equipped with an acceptable timing device that will not permit the batch to be discharged until the specified mixing time has elapsed. Truck mixers shall be equipped with counters by which the numbers of revolutions of the drum or blades may be readily verified. The counters shall be read at the time of starting and ending of mixing at mixing speeds.

B. The truck mixer when loaded with concrete shall not contain more than 63% of the gross volume of the drum. The mixer shall be capable of combining the ingredients of the concrete into a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity.

C. The stationary mixer, when loaded at the manufacturer's guaranteed mixing capacity, and the concrete mixed for the time prescribed, shall be capable of combining the ingredients of the concrete into a thoroughly mixed and uniform mass and discharging the concrete with satisfactory uniformity.

D. The agitator, when loaded not to exceed 80% of gross drum volume, shall be capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity.

M4.02.10 Mixing and Delivery.

A. Ready-mixed concrete shall be mixed and delivered to the point designated by the Engineer by means of one of the following combinations of operations.

1. Mixed completely in a stationary mixer and the mixed concrete transported to the point of delivery in a truck agitator or in a truck mixer operating at agitator speed or in nonagitating equipment when approved by the Engineer.

2. Mixed completely in a truck-mixer at the point of delivery under the supervision of the Resident Engineer or his/her designated assistant, one of whom shall certify on a delivery slip that he/she observed the complete mixing of the concrete.

B. Truck mixers and truck agitators shall be operated within a capacity not to exceed 63%, or 80% respectively, of the gross volume of the drum and at a speed of rotation for mixing or agitating as designated by the manufacturer of the equipment. A truck mixer or truck agitator used for transporting concrete that has been completely mixed in a stationary mixer shall be operated within the limits of capacity and speed of rotation designated by the manufacturer for agitating, except that the agitator capacity in no event exceeds 80% of the gross drum volume.

C. When a stationary mixer is used for the complete mixing of the concrete, the mixing time for mixers having a capacity of 7.6 cubic meters or less shall be not less than 60 seconds. For mixers of more than 7.6 cubic meters capacity, the mixing time shall be determined by the Engineer. The time is valid provided mixer efficiency tests prove the concrete is satisfactory for uniformity and strength. Mixing time shall be measured from the time all cement and aggregates are in the drum. The batch shall be so charged into the mixer that some water will enter in advance of cement and aggregates, and all water shall be in the drum by the end of the first one-fourth of the specified mixing time.

D. When a truck mixer is used for complete mixing, each batch of concrete shall be mixed for not less than 70 nor more than 100 revolutions of the drum or blades at the rate of rotation designated by the manufacturer of the equipment on the metal plate on the mixer as mixing speed. Additional mixing, if any, shall be at the speed designated by the manufacturer of the equipment as agitating speed. All materials including adding water shall be in the mixer drum before actuating the revolution counter for determination of number of revolutions of mixing.

E. When a truck mixer or truck agitator is used for transporting central-mixed concrete, or when all ingredients including water have been added to the truck mixer at the batching plant, the drum shall be constantly rotated at the agitating speed designated by the manufacturer of the equipment, both during transport and while on the project prior to discharge, except during the period required for mixing.

F. When a truck mixer or truck agitator is used for transporting concrete, the concrete shall be delivered to the site of the work and discharge shall be completed within 90 minutes after the addition of the cement to the aggregates. Each batch of concrete delivered at the job site shall be accompanied by a time slip issued at the batching plant, bearing the time of charging of the mixer drum with cement and aggregates. In hot weather or under conditions contributing to quick stiffening of the concrete or when the temperature of the concrete is 29 °C or above, the time between the introduction of the cement to the aggregates and discharge shall not exceed 1 hour. When a truck mixer is used for the complete mixing of the concrete, the mixing operation shall begin within 30 minutes after the cement has been added to the aggregate.

When it is determined that more than 90 minutes will be required to batch and completely discharge the load, an alternate method of delivery and mixing will be permitted. The truck mixer will be charged at the batching plant with reasonably dry aggregates and cement but no mixing water. The required amount of mixing water shall be carefully introduced into the truck mixer at the job site and the batch of concrete mixed as outlined above. Under such conditions one hour shall be allowed for the discharge of the load, computed from the time the mixing water has been added to the batch and the mixing begun.

The concrete when discharged from truck mixer sand truck agitators shall be of the consistency and workability required for the job. The rate of discharge of the plastic concrete from the mixer drum shall be controlled by the speed of rotation of the drum in the discharge direction with the discharge gate fully open.

All wash water shall be removed from truck mixers and truck agitators prior to charging with a fresh load.

G. When approved by the Engineer, central-mixed concrete which is designed for the purpose maybe transported in suitable nonagitating equipment.

H. Concrete may be tempered only once before the initial set with the permission of the Engineer and only with an approved superplasticizer to bring the slump back to within the specification. The concrete shall be mixed thoroughly according to the manufacturer's recommendation. Concrete shall not be re-tempered by adding water. Any batch of concrete that does not conform to the specification with respect to delivery time, temperature, slump or entrained air content shall be rejected.

I. When nonagitating equipment is used for transportation of concrete:

a) Bodies of equipment shall be smooth, water-tight, metal containers equipped with gates that will permit control of the discharge of the concrete. Covers meeting the approval of the Engineer shall be provided for protection against the weather.

b) The concrete shall be delivered to the site of the work in a thoroughly mixed and uniform mass and discharged with a satisfactory degree of uniformity. Slump tests of representative samples taken during the discharge shall not differ by more than 50 millimeters. Discharge shall be completed within 30 minutes after introduction of the mixing water to the cement and aggregates.

II. Concrete delivered in outdoor temperatures lower than 4 °C shall arrive at the work having a temperature not less than 15 °C nor greater than 32 °C.

M4.02.11 Storage and Handling of Materials.

All materials shall be stored and handled in an approved manner.

A. Cement.

Cement shall be fully protected against moisture and any cement damaged by exposure shall not be used.

Cement shall be emptied directly from the shipping packages into the skip of the mixer, except when bulk cement is used. The cement discharge chute at the aggremeter shall be so arranged that there will be no possibility of loss of cement in passing through it.

B. Aggregates.

Aggregates in stockpiles shall be placed on firm well-drained ground. The piles shall be of such shape and size that materials may be handled and stored without becoming dirty or mixed with deleterious substances. Aggregates from different sources or different grading shall be kept in separate stockpiles.

Coarse aggregate will be handled and stored to produce minimum segregation of sizes. Fine aggregate will be handled in such a way as to prevent the loss of fines. Aggregate shall be induced into the aggremeter in an approved manner complying with required gradation.

Storage and handling of aggregates shall be done in a manner to ensure a uniform moisture content satisfactory for proper control of the consistency of the mix. Frozen aggregates shall not be used.

Aggregates shall be taken continuously from one source in filling the compartments of the batcher bin, and no change of source of any of the aggregates shall be permitted without the consent of the Engineer.

The Department reserves the right to prohibit the use of aggregates from any plant, pit quarry or deposit where the character of the material method of operation or rate of production is inadequate.

When aggregate is proportioned in the batching plants and transported by trucks to the paving mixer, the compartments in the trucks shall be of sufficient size to prevent spilling from one compartment to another either in transit or when emptying the load into the skip of mixer.

M4.02.12 Cold Weather Concrete.

Concrete mixed or placed when the air temperature is below 5 °C will be considered cold weather concrete and will require special treatment. In general the special treatment is indicated below.

When concrete operations are permitted when the air in the shade and away from artificial heat is 5 °C or lower temperature, the mixing water and/or aggregates may be heated (prior to cement being added) by approved methods so that the temperature of the aggregates and water mixture is not less than 20 °C nor more than 60 °C. The temperature of the concrete shall not be less than 15 °C nor more than 32 °C at the time of placing it in the forms. The heating shall be done in a manner to preclude the occurrence of overheated areas which might result in damage to the materials. Any material containing frost or lumps of hardened material shall not be used.

M4.02.13 Test Specimens.

A. Samples of concrete shall be obtained in accordance with the Standard Method of Sampling Fresh Concrete (AASHTO T 141) in the case of individual samples secured to determine uniformity of consistency for approval of the mixer or agitator. In securing individual samples to determine uniformity of consistency, AASHTO T 141 shall be followed but the requirements shall be so modified as to permit obtaining and testing of each of three samples: one at approximately the beginning, one at approximately the

midpoint and one at approximately the end of discharge. Slump and air content will be measured and recorded when concrete cylinders are fabricated.

B. For the purpose of making tests to determine the flexural or compressive strength of concrete, the Engineer reserves the right to cast such test beams or cylinders as he/she deems necessary.

The Contractor shall furnish concrete and such assistance as the Engineer may require.

After the fabrication of concrete cylinders by the Engineer, the concrete cylinders shall be protected and cured on the project by the Contractor in accordance with AASHTO T23 and as directed by the Engineer without additional compensation. The Contractor shall furnish and maintain, without extra compensation, a protected environment to provide initial curing of all concrete cylinders at the project. The protective environment shall be available at each site where concrete is placed and then maintained by the Contractor until such time that all concrete cylinders have been transported to the laboratory for testing. The Engineer shall approve each protective environment prior to the beginning of any project concrete placement.

The protective environment shall be shielded from direct sunlight and radiant heating devices. The protective environment shall be capable of maintaining the temperature for the stored concrete cylinders in the range between 16 and 27ºC and loss of moisture from the cylinders shall be prevented.

When moving the concrete cylinders into the protective environment, precautions shall be taken to avoid any damage to the freshly made concrete cylinders.

The protective environment for the concrete cylinders shall consist of tightly constructed, firmly braced wooden boxes, damp sandpits, temporary building at construction sites, wet burlap covered with plastic in favorable weather, or heavyweight closed plastic bags. Other suitable methods may be used, upon approval by the Engineer, provided that the foregoing requirements limiting concrete cylinder temperature and moisture loss are met.

Storage temperature shall be regulated by means of ventilation, or thermostatically controlled cooling devices, or by using heating devices such as stoves, light bulbs, or thermostatically controlled heating elements. A temperature record of the concrete cylinders shall be established by means of maximum-minimum thermometers.

After finishing the concrete cylinders, they shall be covered and placed immediately into the protective environment where they will remain undisturbed for the initial curing period.

Concrete cylinders may also be immersed in saturated limewater immediately after finishing and placed in a protected environment where the temperature shall be maintained in the range of 60 to 80°F and loss of moisture from the cylinders shall be prevented until just prior to transporting the cylinders from the project. This curing is not acceptable for specimens in cardboard molds or molds which expand when immersed in water. Concrete cylinders that are to be transported to the laboratory for standard curing before 48 hours shall remain in the molds in a moist environment until they are received in the laboratory, demolded and placed in standard curing. Concrete cylinders that will be transported to the laboratory for standard curing after 48 hours age may be cured in the protective environment without demolding provided that the loss of moisture is prevented until the time of transportation and testing. Concrete cylinders shall not be exposed to dripping or running water.

All concrete cylinders shall be transported to the laboratory for standard curing and testing by the Department personnel within six days of the time of cylinder fabrication.

When the sequence of the construction operation is dependent upon the development of strength in concrete previously placed the specimens taken for this purpose shall be further cured after 24 hours as required in Section 9 of AASHTO T 23 by the Contractor, without additional compensation, under the direction of the Engineer.

C. Consistency tests shall be made when designated by the Engineer. Determination of air content shall be made as designated by the Engineer if air-entraining cement or an air-entraining admixture is used. If the measured consistency or air-content falls outside the limits specified, check list shall be made. In the event of a second failure, the Engineer may refuse to permit the use of the load of concrete represented.

D. Methods of testing ready-mixed concrete shall be in accordance with the following methods of the American Association of State Highway and Transportation Officials:

1. Sampling Fresh Concrete (AASHTO T 141).
2. Weight Per Cubic Foot, Yield and Air Content (Gravimetric) of Concrete (AASHTO T 121).
3. Flexural Strength of Concrete (Using Simple Beam with Third Point Loading) (AASHTO T 97).
4. Compressive Strength of Molded Concrete Cylinders (AASHTO T 22).
5. Making and Curing Concrete Compression and Flexure Test Specimens in the Field

(AASHTO T 23).

6. Slump Test for Portland Cement Concrete (AASHTO T 119).
7. Air Content of Freshly Mixed Concrete by the Pressure Method (AASHTO T 152).
8. Air Content of Freshly Mixed Concrete by the Volumetric Method (AASHTO T 196).

E. Strength tests will be performed to determine concrete strength compliance for the project. The concrete cylinders must be fabricated in accordance with the sampling schedule as specified in the Materials Manual; the number of concrete cylinders fabricated will depend on the number of ages at which they are to be tested. Test cylinders shall be cured under controlled conditions as described in Article 9.3 of AASHTO T23 and tested at the age of 28 days and/or other ages as specified. A test is defined as the average strength of two concrete cylinders of the same age, fabricated from a sample taken from a single batch of concrete.

F. Individual strength tests shall not fall below the specified strength by more than 3.5 MPa. All concrete represented by the compression test that indicates a compressive strength of more than 3.5 MPa below the specified 28-day strength will be rejected and shall be removed and replaced with acceptable concrete. However, if the Contractor, at the Contractor's expense, may obtain and submit evidence as outlined below, acceptable to the Engineer, that the strength and quality of the concrete placed in the work is acceptable, then the concrete will be permitted to remain in place and the Contractor will be paid at a reduced price as outlined below.

G. If three consecutive standard concrete cylinders tests (AASHTO T22) taken on the jobs from the same plant for the same mix design of concrete fail to meet the strength requirement, the plant shall submit remedial actions for all future production until the source of the problem can be identified and corrected, or new trial batches can be performed. When the average of three consecutive tests, falls to less than 1.0 MPa above the specified strength or any single test falls more than 1.4 MPa below the specified strength, the plant shall make corrective changes in the materials, mix proportions or in the concrete manufacturing procedures, at the plant's expense, before placing additional concrete of the same mix design. Such changes shall be subjected to the approval of the Engineer prior to use.

H. Evaluation and Acceptance of Concrete

The strength of the concrete will be considered satisfactory provided that the average of all sets of three consecutive test results of the same concrete mix equal to or exceed the required specified strength f'c, and no individual test result falls below the specified strength f'c by more than 3.5 MPa.

Non-destructive testing will not be permitted in lieu of compressive strength tests of concrete cylinders, air content tests by the pressure method, slump or other test for evaluation and acceptance of concrete placed on the projects. Coring is the only acceptable method to determine the in-situ characteristics of concrete. The size of the core shall be a 100 mm finished diameter for concrete with 20 mm or less aggregate and 150 mm finished diameter for concrete with aggregate greater than 20 mm. The length of the concrete core, when capped, shall be as nearly as practicable twice its diameter. The test specimens shall be submerged in lime-saturated water at 23 ± 1.7°C for at least 40 hours immediately prior to making the compression test.

This method will not be permitted if the Department determines coring would be harmful to the integrity of the structure. Cores, if approved by the Department, will be obtained by the Contractor and witnessed by the Engineer in accordance with AASHTO T24 and delivered to Research and Materials for testing in accordance with AASHTO T22. If the Department approves the request for strength analysis by coring, the results obtained will be accepted by both parties as conclusive proof of in-situ concrete strength and will supersede all other strength data for the concrete represented by that placement. Cores shall be obtained no later than 50 days after initial placement. All reinforcing steels shall be located with a pachometer around the proposed coring locations prior to the coring operation. The Department shall approve the locations to be cored. and all costs associated with the coring operation including the repair of cored area shall be the responsibility of the Contractor. The Contractor shall patch the core holes with low slump mortar, similar to that used in the concrete, immediately after coring, to the satisfaction of the Engineer. Acceptance by core method requires that the average compressive strength of three cores from the same concrete placement be equal to or exceed the specified strength with no single core less than 85 percent of the specified strength.

These cores may be subjected to petrographic analysis, at the expense of the Contractor, to determine if there is microscopic evidence that identify the constituents of concrete, possible reasons for the strength deficiency of the in-situ concrete, if any, and to provide a basis for assessing the quality and long term durability of the in-situ concrete. The results of the petrographic analysis will be considered in

conjunction with the results of concrete cylinders to determine if the concrete can remain in place or has to be removed.

Concrete with cylinder or core compressive strengths (fc) which failto meet acceptance level requirements shall be evaluated for structural adequacy at the Contractors' expense. The Department shall review all production records, the concrete test records, petrographic analysis report, field notes, and the placement records for the concrete in question. If the material is found to be adequate to remain in place, payment shall be adjusted in accordance with the following formula:

Pay adjustment for substandard concrete, $P = 2(fc-f'c)(UP)(Q)/(f'c)$

Where f'c = Specified minimum compressive strength at 28 days.

fc = Substandard concrete cylinder compressive strength at 28 days or compressive strength of substandard concrete cores determined by AASHTO T-22.

P = Pay adjustment for substandard concrete.

Q = Quantity of concrete represented by the acceptance cylinders tested.

UP = Unit contract price or the lump sum breakdown price per cubic meter for the class of concrete involved.

M4.02.14 Precast Units.

Precast concrete units shall be manufactured of air-entrained 30 MPa - 20 mm - 390 kg cement concrete, true to line, plane and dimensions, in accordance with the following special requirements:

A. Plant Requirements.

The precast manufacturing plant shall be approved by the Department prior to manufacturing, and be certified by either the National Precast Concrete Association (NPCA) Plant Certification Program, or the Precast/Prestressed Concrete Institute (PCI) Plant Certification Program for the category of product being produced. The cement concrete production and precast product fabrication shall be produced at a single plant site operated by a single company.

The units shall be manufactured in an approved enclosed building under the Engineer's control and inspection with a guaranteed provision to meet the requirements for curing and protecting the concrete as specified.

The concrete shall be proportioned as specified in M4.02.06 and mixed in accordance with M4.02.10. No delay or shutdown of over 30 minutes duration in continuous filling of individual forms will be allowed. The units shall be cast true to line and dimensions, free from checking, cracking, voids, surface honeycombing and without requiring additional rubbing or patching.

All steel reinforcement (bars or welded wire fabric) shall be epoxy coated (M8.01.7) or galvanized steel (M8.01.8), conforming to the respective materials specifications.

B. Forms.

As specified below metal or wood forms of tight, rigid construction, true to shape, and with smooth finish shall be used. Concrete forms may be used if approved by the Engineer. The forms shall be oiled in any approved manner. Re-use of old, worn, or misshapen form, will not be allowed.

Bounds	Wooden or wooden-faced; Metal or metal-faced
Catch Basins & Manholes	Metal or metal-faced
Cribbing	Metal or metal-faced
Curb	Wooden or wooden-faced
Curb corners	Wooden or wooden-faced
Edging	Wooden or wooden-faced
Railings	Wooden or wooden-faced
Posts	Wooden or wooden-faced; Metal or metal-faced
Box Culverts	Metal
Light Foundations	Metal
Median Barrier	Metal
Retaining Walls	Metal
Noise Barrier Panels	Metal
Pull Boxes	Metal
Handholes	Metal

C. Vibration.

Vibrators shall be provided and used as specified in 901.65C and as directed by the Engineer. Prolonged vibration shall be avoided in order to prevent surface finish susceptible to crazing. Units showing surface checking or crazing will be rejected.

D. Protection and Curing.

The units shall be cured either by steam or water for a sufficient length of time for the concrete to obtain the minimum compressive strength.

1. Steam Curing.

Two to four hours after the concrete has been placed and attained the initial set, the first application of steam shall be made. Forms shall be removed after the units have been steam cured for 24 hours.

The steam shall be at 100% relative humidity to provide moisture for proper hydration of cement. The steam shall be directly applied onto the concrete. During application of steam the ambient temperature shall increase at the rate not to exceed 22 C° per hour until a minimum temperature of 55 °C is reached.

When discontinuing the steam application, the ambient temperature shall be decreased at the rate of 22 C° per hour until a temperature of 11 C° above the atmospheric temperature has been attained. The concrete shall not be exposed to temperatures below freezing for a minimum of 6 days after casting.

2. Water Curing.

The units may be water cured with water, saturated material or other acceptable or approved methods that will keep the units moist for a period of 5 days. Under no condition will the use of curing compounds be permitted.

Concrete delivered in outside temperatures lower than 4 °C shall arrive at work having a temperature not less than 15 °C nor greater than 32 °C. Water and aggregates shall be heated if necessary but the water shall not be heated above 60 °C The use of direct heating torch in mixer shall not be approved.

3. Protective Coating.

A protective coating approved by the Engineer shall be used on Curb, Curb Corners, Edging, Railings and Posts.

After the concrete is at least 14 days old and thoroughly dry, the surface shall be cleaned to remove all oil, grime and loose particles which would prevent the protective compound from penetrating the concrete. Immediately before the application of the compound an air blast shall be directed over the surface to be treated so that all dust will be removed and then treated as follows:

The rate and number of applications for each unit shall be in accordance with the manufacturer's recommendations.

E. Finish and Color.

Edging curb corners, precast fence rails and similar units shall be rub finished in the following manner:

After the concrete has properly hardened, the exposed surfaces shall be rubbed with a No. 16 carborundum stone or an abrasive of approved equal in a manner to fully remove cement enamel finish and expose a durable sand grain finish satisfactory to the Engineer. No cement shall be used in the rubbing process.

The color and finish of these units shall be uniform and shall conform to those of adjacent work in their final position.

F. Testing and Sampling.

Representative test specimens of the concrete shall be taken by the Engineer. No precast units will be shipped to a project until the test specimens cured as required in M4.02.13 show a compressive strength of 30 megaPascals.

G. Inspection.

All precast units shall be subject to inspection at the point of manufacture and on the project and any units showing defects or damage before the completion of the project shall be removed and replaced at the expense of the Contractor.

H. Quality Control.

The Contractor shall provide quality control in the form of personnel, equipment and laboratory and office space.

1. Personnel:

There shall be sufficient personnel trained and certified to perform the tests listed under M4.02.13, Part D. The certification required shall be the American Concrete Institute (ACI) Field Technician Level I certification, or Precast/Prestressed Concrete Institute (PCI) Technician/Inspector Level I or higher.

2. Equipment:

Air Content Meter Type A or B (AASHTO T 152)
Air Content Meter Volumetric Method (AASHTO T 196)
Slump Cone (AASHTO T 119)
Cylinder Molds (AASHTO T 205)
Concrete Testing Machine (AASHTO T 22)
Screening Sieve (AASHTO T 27, T 11)
Curing Box (AASHTO T 23)
And other necessary items such as ovens, scales, hot plates, pans, etc., to perform tests.
Portable Temperature Recorders

3. Laboratory:

The laboratory will be a room of sufficient size to house all equipment and to adequately perform all these tests. The room shall have either a separate moisture storage room or curing box for concrete cylinders and it shall be thermostatically controlled to maintain 23 °C. The laboratory room shall be heated and air conditioned to maintain 23 °C. It shall include a deck and file cabinet for proper record keeping, and have good lighting and ventilation. This room shall be kept for testing and quality control and not used for any other purpose. An additional desk and file cabinet shall be provided for the exclusive use of the Engineer.

No exception from these requirements will be allowed without the expressed written permission of the Engineer.

M4.02.15 Cement Mortar.

Mortar shall be composed of one (1) part Portland cement and two (2) parts of sand by volume with sufficient water to form a workable mixture. Cement, sand and water shall conform to M4.01.0, M4.02.02A and M4.02.04, respectively.

M4.02.15 Precast Drainage Structures

Precast manholes and catch basins shall conform to the requirements of AASHTO M199M. Special manholes shall meet the requirements of M4.02.14, Precast Units. After curing a minimum of 14 days, the outside surface of the tapered or cone section of precast cement concrete drainage structures shall be dried, cleaned and coated with a coal tar emulsion meeting the requirements of M3.03.3 Protective Seal Coat Emulsion.